DOI: https://doi.org/10.52756/ijerr.2026.v50.011 *Int. J. Exp. Res. Rev.*, Vol. 50: 134-150 (2026)

Review Article | *Peer Reviewed* | *Open Access*

International Journal of Experimental Research and Review (IJERR)
© Copyright by International Academic Publishing House (IAPH)
ISSN: 2455-4855 (Online)
www.iaph.in
ISSN 2455-4855

Influence of Nanoparticles on Heat Transfer in Helical Coil Heat Exchangers: A Comprehensive Review

Shubhangi S. Tayde* and Jagdeep M. Kshirsagar

Department of Mechanical Engineering, Maharashtra Institute of Technology, Chhatrapati Sambhajinagar, Maharashtra, India

E-mail/Orcid Id:

ST, shubhangitayde@gmail.com, https://orcid.org/0009-0005-0163-0842; *JK,* jmkshirsagarmit@gmail.com, https://orcid.org/0000-0001-8988-2377

Article History:

Received: 14th Dec., 2025
Accepted: 30th Mar., 2026
Published: 30th Apr., 2026

Keywords:
Helical coil heat exchangers (HCHEs), Nanofluids, Heat transfer performance, Hybrid nanofluids, Optimization strategies, Industrial applications.

How to cite this Article:
Shubhangi S. Tayde and Jagdeep M. Kshirsagar (2026). Influence of Nanoparticles on Heat Transfer in Helical Coil Heat Exchangers: A Comprehensive Review. *International Journal of Experimental Research and Review, 50*, 134-150.
DOI:
https://doi.org/10.52756/ijerr.2026.v50.011

Abstract: The helical coil heat exchangers (HCHEs) remain a primary industrial component because they enable efficient heat transfer within their compact design. Due to the helical structure of the enhanced tube, secondary flows and Dean vortices are generated, thereby increasing heat transfer by convection. Over the last decade, nanofluids, incorporating nanoparticles such as Al_2O_3 (Aluminum oxide), MgO (Magnesium oxide), CuO (copper oxide), TiO_2 (Titanium dioxide), and carbon nanotubes (CNTs), have been identified as optimal working fluids for improving heat transfer in HCHEs. The effect of the nanoparticles' size, shape and concentration, as well as the flow velocity and temperature, is discussed in the framework of this review on heat transfer enhancement. Research has shown that nanofluids could enhance thermal conductivity and heat transfer coefficients by 20 to 50 percent, thereby improving system performance. However, some of the disadvantages of nanoparticles include instability, elevated fluid viscosity, pressure drop and high production costs, hence limiting their application. This paper explores possible solutions, including improvements to hybrid nanofluids, optimization strategies and applications in industry. In this review, HCHEs and nanofluid technology are connected to discuss the current research gaps and potential paths for the future that may help to advance the commercialization of this efficient and green thermal control approach.

Introduction

Helical Coil Heat Exchangers (HCHEs) are critical components in thermal management systems, widely used in industries such as power generation, refrigeration, chemical processing, and HVAC systems (Hasan et al., 2022; Tavousi et al., 2023; Babar et al., 2024). Their unique helical geometry, characterized by secondary flow patterns known as Dean vortices, significantly enhances heat transfer by promoting fluid mixing and disrupting thermal boundary layers. Compared to traditional straight-tube heat exchangers, HCHEs offer superior thermal efficiency, compact design, and the ability to operate under high-pressure and high-temperature conditions (Nam et al., 2023).

The geometry of the coil plays a crucial role in determining the heat transfer performance of HCHEs. Key geometric parameters include the coil diameter (D), the tube internal diameter (d), the pitch (axial turn spacing), and the number of turns (N). Smaller coil diameters enhance secondary flow effects, improving heat transfer, while the tube diameter influences the flow area and Reynolds number, affecting both pressure drop and heat transfer rates. The pitch directly affects the exchanger's flow pattern and compactness, with tighter pitches leading to better heat transfer but

*Corresponding Author: shubhangitayde@gmail.com

This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License.

higher pressure drops. Additionally, increasing the number of turns increases the heat-transfer surface area, further improving performance (Wei et al., 2021; Nam et al., 2023; Babar et al., 2024).

Nanofluids, suspensions of nanoparticles (1–100 nm) in base fluids like water, ethylene glycol, or oil, offer enhanced thermal conductivity and convective heat transfer coefficients compared to conventional fluids. Common nanoparticles include Al_2O_3, CuO, TiO_2 and carbon nanotubes (CNTs). For instance, water enhanced with 1% Al_2O_3 nanoparticles shows a 20–30% increase in thermal conductivity, reducing thermal equilibrium time in HCHEs (Tavousi et al., 2023; Shaik et al., 2024; Prasad & Kumar, 2024; Xu et al., 2025).

However, there are some limitations like nanoparticle agglomeration, higher fluid viscosity, and pressure drop across the nanoparticle layer that pose challenges in their usage and practice, besides the high costs of producing such fluids (Prasad & Kumar, 2024; Xu et al., 2025).

Helical Coil Heat Exchangers

HCHEs use their helical structure to enhance heat transfer through Dean vortices and secondary flow. Other additives include nanoparticles such as Al_2O_3, CuO, TiO_2 and CNTs, which, when dispersed in base fluids, enhance thermal conductivity. Such

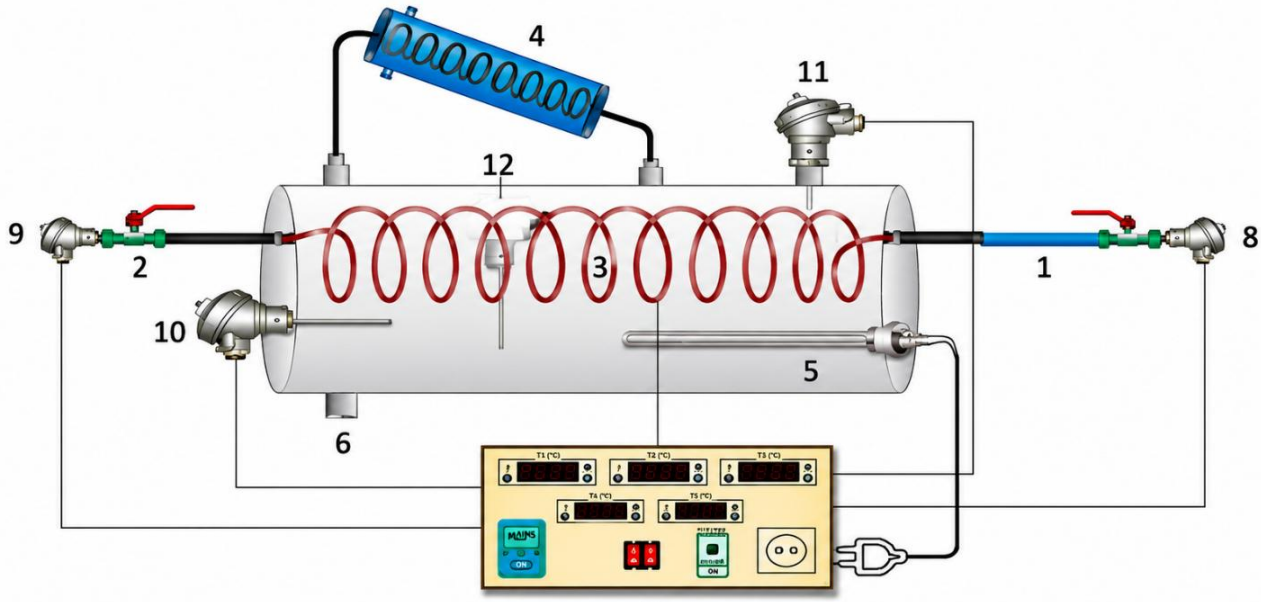

Figure 1. Schematic of the experimental heat exchanger (Karimi Bakhtiyar et al., 2023).

There are other types of inserts, such as twisted tapes, coiled wires, and fins, which can be installed in the inner passages to alter the flow behaviour and increase turbulence. By incorporating them into nanofluids and HCHE geometries, inserts can become an avenue for improved efficiency (Ramadhan et al., 2020; Alshahrani et al., 2021; Hasan et al., 2022; Tavousi et al., 2023; Babar et al., 2024). This review aims to analyze the influence of nanoparticle loading and the geometry of heat- and mass-transfer components on the performance of HCHE, with reference to nanoparticle properties, including size, shape and concentration, and to operating parameters such as Reynolds number and temperature. It also provides solutions to issues such as nanofluid instability and cost constraints, with recommendations including the use of hybrid nanofluids and artificial intelligence to optimize nanofluid utilization for industrial applications (Shaik et al., 2024; Prasad & Kumar, 2024; Xu et al., 2025).

nanofillers, for example, 1 wt% Al_2O_3 in water, can improve thermal conductivity by 20–30%, resulting in reduced thermal equilibrium time and overall system improvement (Ali & Salam, 2020; Hasan et al., 2022; Tavousi et al., 2023; Nam et al., 2023; Babar et al., 2024).

DOI: https://doi.org/10.52756/ijerr.2026.v50.011

These include aluminum oxide (Al_2O_3), copper oxide (CuO), titanium dioxide (TiO_2) and carbon nanotubes (CNTs), which possess high thermal conductivity, thereby improving heat transfer performance. Experimental investigations showed that the use of water containing 1% by volume of Al_2O_3 nanoparticles increases thermal conductivity by 20–30%, thereby reducing the thermal equilibrium time in heat exchangers. These modifications improve heat transfer rates and enhance overall system performance in Helical Coil Heat Exchangers (HCHEs) (Wei et al., 2021; Tavousi et al., 2023; Shaik et al., 2024; Prasad & Kumar, 2024; Xu et al., 2025).

Geometric Factors Influencing HCHE Performance

Therefore, the performance of HCHEs depends on geometric parameters and operating conditions involved in the process. It has been observed that smaller coil diameters lead to enhanced secondary flow patterns, which improve heat transfer performance but also increase pressure drop. These factors must be balanced carefully to achieve maximum thermal effectiveness. The internal diameter of the tube determines the flow area and Reynolds number, which directly influence heat transfer and pressure drop characteristics. Smaller tube diameters increase turbulence and heat transfer rates but require higher pumping power (Khan & Arasu, 2019; Qiu et al., 2020; Wei et al., 2021; Hasan et al., 2022; Nam et al., 2023; Babar et al., 2024).

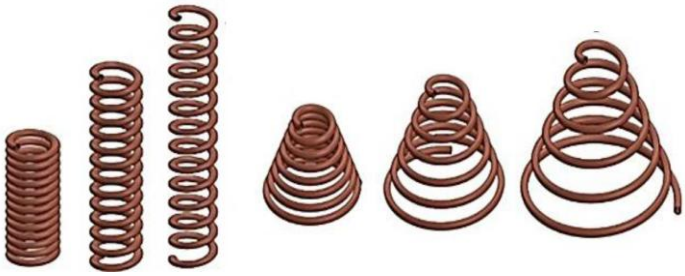

Figure 2. Schematic diagram of the different coils (Karimi Bakhtiyar et al., 2023).

Close pitch arrangements enhance convective heat transfer; however, they also increase pressure losses. Proper pitch selection is therefore important for achieving stable and efficient system performance. Additionally, a higher number of turns increases the heat transfer surface area, thereby improving thermal performance, but it also causes a higher-pressure drop, necessitating optimized heat exchanger designs (Maghrabie et al., 2021; Hasan et al., 2022; Tavousi et al., 2023; Nam et al., 2023).

Role of Nanoparticles in Enhancing Thermal Performance

Some nanoparticles used in the development of nanofluids, typically ranging from 1–100 nm, include Al_2O_3, CuO, TiO_2 and CNTs, which enhance the thermal performance of HCHEs when dispersed in base fluids. Nanoparticles improve thermal conductivity through mechanisms such as Brownian motion, enhanced surface area-to-volume ratio, and improved energy transport characteristics. Studies have reported that nanofluids can enhance heat transfer coefficients by up to 50% in HCHEs under laminar flow conditions. The combined effect of helical geometry and nanoparticle-enhanced fluids offers significant potential for efficient thermal system applications (Ali & Salam, 2020; Maghrabie et al., 2021; Hasan et al., 2022; Tavousi et al., 2023; Nam et al., 2023; Prasad & Kumar, 2024).

Recent Advances in HCHE Design

Modernization of Helical Coil Heat Exchangers (HCHEs) has focused on enhancing thermal performance through advanced analytical, numerical, and experimental techniques. One of the major developments is the use of nanofluids as working fluids, which improve thermal conductivity and convective heat transfer coefficients. Experimental investigations have shown nearly 50% enhancement in heat transfer coefficients with nanofluids containing Al_2O_3, CuO, and CNTs. Various coil configurations, such as single helical, double helical, variable pitch, and twisted tape inserts with integral or quarter-cycle helical angles, have also been developed to intensify secondary flow and Dean vortices, thereby improving heat transfer performance. Variable pitch designs help control the axial spacing between coil turns, influencing turbulence intensity and hydraulic drag (Ali & Salam, 2020; Wei et al., 2021; Hasan et al., 2022; Tavousi et al., 2023; Nam et al., 2023).

These advancements are further supported by CFD analysis, optimization techniques, and machine learning approaches, which help optimize

DOI: https://doi.org/10.52756/ijerr.2026.v50.011

parameters such as coil diameter, tube size, pitch, and nanoparticle concentration. Furthermore, the use of inserts such as twisted tapes and wire coils, along with nanofluids, enhances boundary-layer disruption and surface interactions, leading to superior heat-transfer characteristics. These developments indicate strong potential for the application of nanoparticle-enhanced fluids combined with optimized helical geometries in next-generation HCHEs for energy-intensive industrial applications (Batista & Rajendran, 2023; Shaik et al., 2024; Prasad & Kumar, 2024; Xu et al., 2025).

Nanofluids in Heat Exchangers

Nanofluids consist of nanoparticles in the size range of 1–100 nm dispersed in base fluids, providing superior heat transfer performance compared to conventional fluids. The high thermal conductivity characteristics of nanoparticles significantly enhance thermal performance and convective heat transfer efficiency. This section focuses on understanding the role of nanofluids, the factors influencing their performance, and the challenges associated with their practical implementation in thermal systems (Ali & Salam, 2020; Maghrabie et al., 2021; Hasan et al., 2022; Tavousi et al., 2023; Prasad & Kumar, 2024).

Mechanisms of Heat Transfer Enhancement

Nanoparticles commonly used in heat transfer applications include aluminum oxide (Al_2O_3), copper oxide (CuO), titanium dioxide (TiO_2), and carbon nanotubes (CNTs) because of their excellent thermal conductivity. These nanoparticles significantly improve the heat transfer efficiency of base fluids such as water, ethylene glycol and oil. Studies have shown that the addition of 1% volume concentration of Al_2O_3 nanoparticles to water can increase thermal conductivity by nearly 20–30%, thereby reducing the thermal equilibrium time in heat exchangers and improving overall thermal performance (Ali & Salam, 2020; Wei et al., 2021; Hasan et al., 2022; Tavousi et al., 2023; Shaik et al., 2024; Prasad & Kumar, 2024).

Table 1. Key Parameters Influencing Nanofluid Performance.

Parameter	Description	Impact on Performance
Base Fluid	Fluid in which nanoparticles are suspended (e.g., water, ethylene glycol, oil).	Water-based nanofluids are preferred for high specific heat, while oil-based nanofluids are suitable for high-temperature applications (Singh & Gupta, 2018; Prasad & Kumar, 2024).
Nanoparticle Concentration	Volume fraction of nanoparticles in the base fluid.	Higher concentrations improve thermal conductivity but increase viscosity and pressure drop (Apertet & Goupil, 2016; Bahiraei et al., 2018; Shaik et al., 2024).
Particle Size	Diameter of nanoparticles (typically 1–100 nm).	Smaller particles provide better dispersion and higher thermal conductivity (Apertet & Goupil, 2016; Prasad & Kumar, 2024).
Particle Shape	Shape of nanoparticles (e.g., spherical, rod-shaped, platelet-shaped).	Non-spherical particles (e.g., rods, platelets) offer greater surface area and improved heat transfer (Singh & Gupta, 2018; Shaik et al., 2024).

DOI: https://doi.org/10.52756/ijerr.2026.v50.011

The effective heat transfer pathways increase due to the formation of nanoparticle conductive networks throughout the fluid medium. Enhanced thermal conductivity improves the heat transfer rate, reduces energy losses, and increases the operational efficiency of Helical Coil Heat Exchangers (HCHEs) (Hasan et al., 2022; Tavousi et al., 2023; Nam et al., 2023; Babar et al., 2024; Xu et al., 2025).

Challenges of Nanofluids in HCHEs

Stability Issues

Nanoparticles in nanofluids tend to agglomerate and settle out over time, adversely affecting heat transfer performance and long-term operational stability. To overcome these challenges, effective stabilization techniques such as surfactants, surface modification and ultrasonic agitation are commonly employed. However, achieving stable nanoparticle dispersion increases the complexity and production cost of nanofluids (Afzal et al., 2018; Ali & Salam, 2020; Tavousi et al., 2023; Shaik et al., 2024; Prasad & Kumar, 2024).

Increased Viscosity and Pressure Drop

The addition of nanoparticles increases the viscosity of base fluids, leading to higher pressure drops across heat exchangers. Consequently, greater pumping power is required to maintain the desired flow conditions. Therefore, the enhancement in heat-transfer performance must be carefully balanced against increased energy consumption. The thermal and hydraulic performance of nanofluids is highly dependent on nanoparticle concentration and operating flow parameters, and these parameters should be optimized for efficient operation (Wei et al., 2021; Hasan et al., 2022; Tavousi et al., 2023; Prasad & Kumar, 2024).

Economic Viability

Certain nanomaterials, such as carbon nanotubes (CNTs) and graphene oxide, are expensive to synthesize and functionalize, which limits their large-scale industrial applications. Therefore, there is a growing need for cost-effective nanofluid production methods that can support commercial-scale implementation while maintaining thermal efficiency (Shaik et al., 2024; Prasad & Kumar, 2024).

Environmental and Safety Concerns

Nanoparticles may pose environmental and health risks because their long-term effects are not yet fully understood. To minimize these concerns, researchers are developing sustainable, eco-friendly, and biodegradable nanofluids that can improve thermal performance while reducing environmental impact and safety hazards (Ali & Salam, 2020; Apertet & Goupil, 2016; Prasad & Kumar, 2024; Xu et al., 2025).

Key Observations

a) Nanoparticle Impact: The enhancement in thermal conductivity strongly depends on the material properties, size, and shape of nanoparticles. Carbon nanotubes (CNTs) exhibit superior thermal conductivity enhancement because of their high aspect ratio and exceptional thermal transport properties. In contrast, titanium dioxide (TiO_2) generally provides lower thermal conductivity enhancement compared to metal oxides such as aluminum oxide (Al_2O_3) and copper oxide (CuO). Optimizing nanoparticle size, shape and material composition is essential for improving heat transfer performance across various thermal applications (Hasan et al., 2022; Tavousi et al., 2023; Shaik et al., 2024; Prasad & Kumar, 2024).

b) Base Fluid Influence: The thermal performance of nanofluids is highly dependent on the selected base fluid. Ethylene glycol (EG) and oil-based nanofluids exhibit better thermal stability and performance under high-temperature conditions compared to water-based nanofluids. Although water-based nanofluids provide excellent heat transfer performance at room temperature, their effectiveness may decrease at elevated temperatures. Therefore, selecting suitable base fluids is important for achieving optimal thermal performance in industrial applications (Ali & Salam, 2020; Maghrabie et al., 2021; Hasan et al., 2022; Prasad & Kumar, 2024).

c) Concentration Trade-off: Increasing nanoparticle concentration enhances thermal conductivity, but it also increases viscosity and pressure drop. Studies have reported that a 1% nanoparticle concentration can improve thermal conductivity by nearly 20–30%, however, viscosity may simultaneously increase by 15–20%, leading to

DOI: https://doi.org/10.52756/ijerr.2026.v50.011

higher pumping power requirements. Therefore, determining the optimal nanoparticle concentration is necessary to achieve maximum thermal enhancement while minimizing hydraulic losses and energy consumption (Wei et al., 2021; Tavousi et al., 2023; Shaik et al., 2024).

d) Hybrid Nanofluids: Hybrid nanofluids containing multiple nanoparticles, such as CuO–Graphene/water nanofluids, demonstrate synergistic thermal enhancement effects. Experimental studies have shown that thermal conductivity can increase by more than 50% using hybrid nanoparticle combinations. Hybrid nanofluids offer improved thermal performance, enhanced stability and improved heat transfer characteristics compared to single-nanoparticle nanofluids. Current research focuses on developing advanced hybrid nanofluids that can overcome stability and cost-related limitations while improving overall system efficiency (Shaik et al., 2024; Prasad & Kumar, 2024; Xu et al., 2025).

Table 2. Thermal Properties of Common Nanofluids.

Authors	Nanoparticle	Base Fluid	Concentration (Vol %)	Thermal Conductivity Increase (%)
Mahian et al. (2013)	Al_2O_3	Ethylene Glycol	2	22–25
Nabeel Rashin & Hemalatha (2013)	CuO	Water	0.5	18–22
Wang et al. (2015)	Al_2O_3	Water	1	15–20
Ahmed & Sharma (2017)	CuO	Engine Oil	1.5	28–32
Shaik et al. (2024)	Graphene Oxide (GO)	Water	0.1	25–30
Danes & Garnier (2011)	CNT	Ethylene Glycol	0.5	40–45

Advancements in Helical Coil Heat Exchangers (HCHXs) Using Nanofluids:

The industrial sector extensively uses Helical Coil Heat Exchangers (HCHXs) because they provide efficient heat transfer, compact construction, and flexibility in handling fluids with different thermal properties. The implementation of nanofluids as working fluids in HCHXs has attracted significant research interest in recent years due to their superior thermal performance. Several studies have investigated the enhancement of heat transfer characteristics in HCHXs using different nanoparticle-based nanofluids (Hasan et al., 2022; Tavousi et al., 2023; Batista & Rajendran, 2023; Babar et al., 2024).

Numerous researchers have confirmed that helical coils generate Dean vortices due to their curved geometry, thereby enhancing heat transfer through improved fluid mixing and secondary flow formation. Studies have shown that the thermal characteristics of helical coils are strongly influenced by geometric parameters such as coil diameter, curvature ratio, and pitch. Experimental investigations revealed that tighter coil pitches improve heat transfer performance by increasing turbulence intensity and enhancing mixing within the exchanger. Numerical analyses further demonstrated that smaller curvature ratios result in higher Nusselt numbers and improved thermal efficiency (Hasan et al., 2022; Wei et al., 2021; Nam et al., 2023).

Researchers also evaluated the thermal and hydraulic performance of conically coiled tubes (CCTs) under constant heat-flux conditions using Al_2O_3/water nanofluids at varying volume concentrations and Dean numbers. The findings indicated that lower coil torsion values improved heat transfer performance. The average heat transfer coefficient increased significantly with increasing Dean number, while the friction factor decreased. Furthermore, increasing nanoparticle concentration from 0.3% to 0.9% enhanced the heat transfer coefficient by nearly 32% at lower Dean numbers and 26% at higher Dean numbers (Tavousi et al., 2023; Nam et al., 2023; Prasad & Kumar, 2024).

DOI: https://doi.org/10.52756/ijerr.2026.v50.011

Recent investigations have also focused on the influence of fins and hybrid nanofluids on HCHX performance. Studies using TiO_2/water and CuO–TiO_2/water hybrid nanofluids in shell-and-helical coil heat exchangers (SHCHEs) demonstrated noticeable improvements in heat transfer coefficients for both finned and finless configurations. Hybrid nanofluids exhibited superior thermal performance compared to single nanoparticle nanofluids, while the addition of fins further enhanced thermal efficiency by improving surface interaction and turbulence generation (Shaik et al., 2024; Prasad & Kumar, 2024).

Researchers have also investigated Fe_3O_4 magnetic nanoparticles experimentally and numerically to assess their effects on the performance of helical heat exchangers. Results showed that Fe_3O_4 nanofluids with higher volume fractions significantly improved heat transfer characteristics. An increase in inlet temperature and nanoparticle concentration enhanced the Nusselt number and overall thermal performance of water–ethylene glycol-based nanofluids in helical coil heat exchangers (Xu et al., 2025).

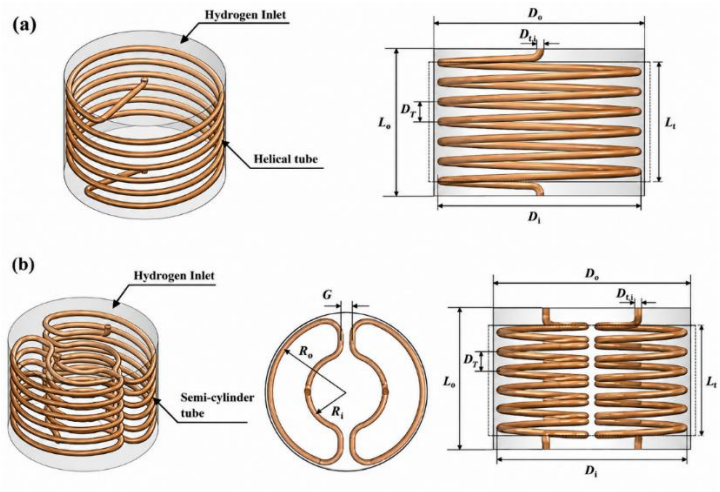

Figure 3. Characteristics of selected geometries for metal hydride reactors: (a) Helical tube heat exchanger and (b) Semi-cylindrical tube heat exchanger (Karimi Bakhtiyar et al., 2023).

The research focused on semi-cylindrical coil heat exchangers (SCHEs) to enhance heat transfer and hydrogen absorption rates in Metal Hydride (MH) storage systems. The semi-cylindrical coil heat exchanger outperformed conventional helical coil systems by achieving nearly 59% faster hydrogen absorption. The study also reported that lower coil pitch values reduced the SCHE system's absorption efficiency by approximately 61% due to changes in thermal and flow distribution characteristics.

Examined the variation in heat transfer rate using modified pitch double-winding tube heat exchangers (Figure 4). The redesigned heat transfer system achieved nearly 22% higher efficiency within the Reynolds number range of 400–2000. The modified pitch coil geometry improved flow distribution and generated stronger secondary flow velocities than conventional coil configurations, resulting in enhanced heat transfer performance and thermal efficiency.

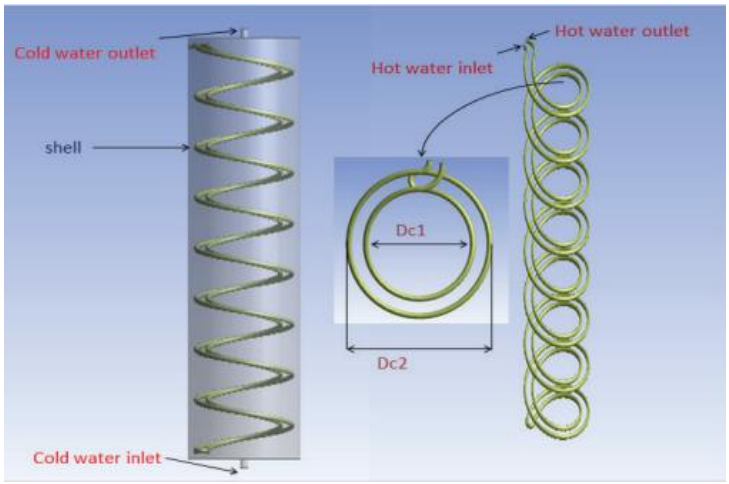

Figure 4. Schematic of shell and double coil tube (Karimi Bakhtiyar et al., 2023).

Nanofluids result from the addition of nanoparticles to the base fluids; hence, the overall thermal properties of fluids are improved, especially the conduction and convective heat transfer coefficients (Ali & Salam, 2020). Nanofluids were initially introduced into the field as fluids whose heat-transfer efficiency across multiple systems could be improved (Hasan et al., 2022). Previous investigations of nanofluid flow with convection under laminar conditions also documented enhancements in nanofluid thermal conductivity and heat transfer rates. These pioneering works provided a basis for learning for succeeding studies in investigating the characteristics of nanofluids in more complicated structures such as helically coiled heat exchangers (HCHXs). It is evident that the thermal conductivity of Al_2O_3 and TiO_2 nanofluids in the heat exchangers is a function of the stability of

DOI: https://doi.org/10.52756/ijerr.2026.v50.011

the dispersed nanoparticles (Tavousi et al., 2023). Studies on the thermo–physical characteristics of GO nanofluids have shown that single–dimensional, slimmer graphene nanoparticles exhibit better thermal properties than metal oxide NPs.

Additional investigations of surfactants' effects on the stability of nanofluids used in HCHXs have shown that incorporating surfactants promotes steady nanoparticle dispersion and lowers pressure drop, thereby increasing overall system efficiency (Nam et al., 2023; Shaik et al., 2024). Literatures on ZnO and combined ZnO-TiO_2 nanofluids for HCHXs have revealed different experiments where thermal conductivity enhancement of 25% is realized than that of conventional fluids (Prasad & Kumar, 2024).

Nanoparticle size, shape, and material properties are significant factors that determine the heat transfer characteristics of nanofluids and reviewed nanofluids in heat exchangers comprehensively and concluded that smaller nanoparticles with higher thermal conductivity materials, such as graphene and metallic oxides, provide better performance (Maghrabie et al., 2021). Numerical simulations were used to investigate the impact of Fe_3O_4-water nanofluids in HCHXs under the influence of a magnetic field (Xu et al., 2025). Their findings indicated that the magnetic field affects nanoparticle motion, thereby enhancing convective heat transfer. Investigations on the effect of nanoparticle shape on thermal performance found that cylindrical and platelet-shaped nanoparticles have better heat transfer than spherical nanoparticles because of their higher surface area. Studies on hybrid nanofluids comprising graphene oxide and copper nanoparticles also reported significant improvements in both thermal conductivity and heat transfer coefficients compared to single-component nanofluids (Shaik et al., 2024).

However, these nanofluids pose several challenges, including instability, increased viscosity, and heat exchanger surface erosion. The aggregation and sedimentation of nanoparticles must be prevented to ensure consistent thermal performance. Improved heat transfer must be weighed against the increased pumping power required. Researchers must seek to optimize the properties of nanofluids for real applications. Long-term stability results for nanofluids in HCHXs indicate that continuous re-suspension or the use of advanced stabilizers is required, as suspensions eventually become prone to settling over prolonged operation (Bahiraei & Hangi, 2014; Apertet & Goupil, 2016; Shaik et al., 2024). To enhance dispersion stability while avoiding the high risk of heat exchanger fouling, proposals involving functionalized nanoparticles have been made for industrial implementation (Prasad & Kumar, 2024).

P-2P-P at P = 20mm (Model a): It has a double-coil heat exchanger system with a pitch arrangement of 20mm (P), 40mm (2P), 20mm (P). This variation increases secondary flow, known as Dean vortices, thereby enhancing turbulence and heat transfer characteristics. Nevertheless, the smaller pitch is likely to increase the pressure drop.

2P-P-2P at P = 20mm (Model b): It has more pronounced pitches similar to Model a but with a reversed order and pitch values, namely: 40 mm (2P), 20 mm (P), 40 mm (2P). This design affects flow in the simplest way, although it can also improve secondary flow rate and provide the best pressure drop.

P-2P-P at P = 30mm (Model c): This model is based at 30 mm and moves between 30 mm (P) and 60 mm (2P) of amplitude. The lower number of turns may slightly reduce heat transfer, but the use of a pitch that alternates seems to enhance aspects of the fluid mix whilst also regulating the pressure drop.

2P-P-2P at P = 30mm (Model d): This model can also be presented as a 60 mm (2P) → 30 mm (P) → 60 mm (2P) pattern. The detachable part with a larger initial diameter reduces flow resistance at the entrance, whereas the smaller-diameter middle part increases turbulence to ensure more efficient heat transfer.

P-2P-P at P = 40mm (Model e): This model changes from 40 mm (P) to 80 mm (2P) and thus there is a lesser number of turns of the coil. Although this reduces the pressure drop compared to smaller-pitch designs, heat transfer capability may be adversely affected.

2P-P-2P at P = 40mm (Model f): Starting from 80 mm (2P), then reducing to 40 mm (P), and again

DOI: https://doi.org/10.52756/ijerr.2026.v50.011

increasing to 80 mm is the best way to reduce the pressure drop. However, lower number of turns may also hamper the formation of secondarily moving flow and therefore, adverse conditions can result.

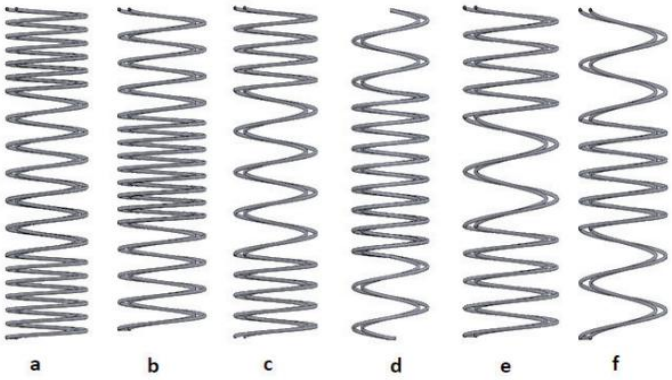

Figure 5. Various models of double heat exchanger a) P-2P-P at P=20mm, b) 2P-P-2P at P= 20mm, c) P-2P-P at P= 30mm, d) 2P-P-2P at P= 30mm, e) P-2P-P at P= 40 mm, f) 2P-P-2P at P= 40mm

Key Observations: Smaller pitches create more turbulence and improve heat transfer rate, but increase pressure drop. Larger pitch means less resistance but it does decrease the efficiency of the unit. As far as the primary flow is concerned, secondary flow arrangements such as P-2P-P and 2P-P-2P increase performance. These pitch variations aid in controlling both heat transfer and pressure drop in double-coil heat exchangers. The above-mentioned approach of varying the pitch value from 1 to infinity shows improved performance and may be implemented in other heat exchanger designs and operating conditions.

Recent studies focus on hybrid nanofluids comprising two or more nanoparticle types to exploit synergistic effects among the nanoparticles. Research on hybrid nanofluids in HCHXs demonstrated higher thermal performance than that achieved with single-nanoparticle nanofluids. Machine learning techniques for predicting the thermal behavior of nanofluids in HCHXs have also been discussed recently. Research on hybrid nanofluids in HCHXs has demonstrated that artificial neural networks can optimize nanoparticle concentration and flow parameters to improve heat transfer efficiency. Employed advanced CFD models to simulate nanofluid flow in HCHXs and to gain more information about the effect of geometric and material parameters on thermal performance. Additionally, reinforcement learning algorithms to design optimal operating conditions for nanofluids in HCHXs, demonstrating potential for real-time system optimization.

Experimental Investigations

Experimental studies have extensively investigated the preparation, stability, thermal conductivity, pressure drop and energy performance of nanofluids in heat exchangers, particularly in helical coil geometries (Hasan et al., 2022; Tavousi et al., 2023; Prasad & Kumar, 2024).

Nanofluid Stability and Preparation: Reliable heat transfer performance requires stable nanofluid preparation. Ultrasonic agitation and surfactants are commonly used methods for achieving uniform nanoparticle dispersion and preventing agglomeration. Studies reported that ultrasonic agitation helps maintain consistent nanoparticle dispersion, while surfactants improve long-term stability of nanofluids (Ali & Salam, 2020; Shaik et al., 2024). Uniform dispersion minimizes sedimentation and ensures stable thermal properties over extended operating durations (Maghrabie et al., 2021; Prasad & Kumar, 2024).

Heat Transfer Performance: Nanofluids have demonstrated improved heat transfer performance in various heat exchanger geometries. Investigations on non-Newtonian nanofluids in Helical Coil Heat Exchangers have reported enhanced thermal performance due to optimized preparation techniques and improved thermo-physical properties (Tavousi et al., 2023; Xu et al., 2025). In another experimental study, Multi-Walled Carbon Nanotube (MWCNT)/water nanofluids used in double-helically coiled tube heat exchangers achieved Nusselt number enhancements of 28%-84% compared to pure water, depending on nanoparticle concentration and operating conditions (Shaik et al., 2024; Prasad & Kumar, 2024).

Coil Geometry and Its Effect on Heat Transfer Rate and Pumping Power

The coil diameter (D) is another factor that determines the heat transfer rate and the power required to pump the heat transfer fluid. Small coil diameter increases secondary flow, which exhibits Dean vortices, thereby raising heat transfer rates by removing thermal boundary layers. The use of coil

DOI: https://doi.org/10.52756/ijerr.2026.v50.011

contributes to the formation of centrifugal forces in the pipe, hence the possibility of enhanced turbulence at relatively small pressure drop is observed, enabling better thermal performance. Nevertheless, smaller coil diameter causes more pressure drop due to its curving, thus portraying a higher flow resistance. This results in more pumping power being required to achieve the desired flow rate in coils than in a coil structure with a more ready layout, where resistance to flow is slightly lower at the same time, this means less turbulent flow and less efficient heat transfer.

The tube's internal diameter (d) also has significant implications for the device's thermal performance. As the tube diameter decreases, for a given volumetric flow rate, the fluid velocity increases, leading to greater turbulence and heat transfer. However, they can exhibit very high pressure drops and low flow rates, especially when the tube diameters are exceedingly small, thereby reducing heat transfer efficiency. On the other hand, larger tube diameters decrease the pressure drop due to lower flow resistance, but they also result in lower flow velocities, thus lower turbulence and, subsequently, a lower heat transfer coefficient. Hence, there is a need to select an appropriate tube diameter that will enhance heat transfer rates while, at the same time, increase pressure losses to an acceptable level.

The other parameters are the pitch (axial turn spacing), which is the distance between two successive turns of the coil. A smaller pitch also makes the coil packager more compact and enhances heat-transfer area and secondary-flow effects due to coil-turn proximity. This enhances heat transfer; nevertheless, if the pitch is made too small, it results in high flow resistance and pressure drop, which may render the system ineffective. On the other hand, a larger pitch also decreases the local pressure drop through an increase in the flow pitch between the turns, while it also reduces the enhancement of secondary flow, which in turn decreases the heat transfer coefficients. Proper selection of the number and geometry of the pitches will improve the heat transferred and the pump's efficiency.

The number of turns (N) in a helical coil is an essential factor in determining the heat transfer rate, as it increases the surface area available for heat exchange. This is because more turns increase the time that the fluid flows along the coil walls, hence gaining more heat from the walls. Moreover, the increase in the number of turns promotes secondary flow effects of Dean vortices, thereby improving fluid circulation and turbulent flow. However, a larger number of turns also increases the coil length, resulting in a high pressure drop and hence more pumping energy is needed. It is therefore necessary to minimize the association between the number of turns and energy cost, even though the heat-transfer advantages tend to slightly outweigh the costs.

The observations regarding coil geometry speak more to the system's heat-transfer efficiency and pumping-power requirements. As seen in the case of smaller coil diameter, tube diameter and pitches, the rate of turbulence and heat transfer increases, but at the same time, the pressure drop and thus the energy consumption is also fairly high. On the other hand, larger geometries decrease flow resistance and pumping power demand but reduce heat-exchange effectiveness. Thus, helical coil flow enhancement has significant implications for heat transfer augmentation, especially in heat exchangers with a specific coil diameter and moderate pitch.

Therefore, the concept of helical coil heat exchangers, with a focus on geometry, plays a significant role in heat exchanger efficiency. Lower diameters and higher pitch ratios improve heat transfer by increasing turbulence and secondary flow, but at a higher pressure drop and pump power consumption. Asymmetric pitch types, P-2P-P and 2P-P-2P, are suitable for balancing heat transfer while reducing energy consumption. Further research should be conducted to investigate extreme geometries and combined nanofluids to enhance key performance metrics of HCHEs in industry.

DOI: https://doi.org/10.52756/ijerr.2026.v50.011

Prior research work

Table 3. The impact of nanoparticles generated by different researchers and their effect on heat transfer is shown below.

Sr. No	Authors	Year	Study Focus/Objective	Nanofluid Type	Key Findings
1.	Wen & Ding	2004	Investigation of convective heat transfer in nanofluids.	Al_2O_3, CuO nanofluids	Nanofluids exhibit higher convective heat transfer coefficients under laminar flow conditions.
2.	Choi et al.	2008	Investigation of convective heat transfer using nanofluids.	Al_2O_3 nanofluid	Al_2O_3 nanofluid exhibits higher convective heat transfer coefficients compared to base fluids.
3.	Jayakumar et al.	2008	Experimental and CFD estimation of heat transfer in helically coiled heat exchangers.	Water-based nanofluids	Nanofluids enhance heat transfer rates in helical coil heat exchangers by increasing thermal conductivity.
4.	Veselovskaya et al.	2010	Performance evaluation of helical coil heat exchangers.	Al_2O_3, CuO nanofluids	Nanofluids enhance heat transfer in helical coils compared to conventional fluids.
5.	Choi et al.	2001	Nanofluid thermal conductivity and viscosity characteristics.	Al_2O_3, CuO, TiO_2 nanofluids	The viscosity and thermal conductivity of nanofluids increase with nanoparticle concentration and nanoparticle type.
6.	Huang et al.	2011	Thermal performance of heat pipes using nanofluids.	Copper-based nanofluids	Copper nanofluids enhance the thermal performance and heat-transfer efficiency of heat pipes.
7.	Eiamsa-ard & Promvonge	2012	Heat transfer enhancement in microchannels with nanofluids.	Al_2O_3, CuO nanofluids	Significant heat transfer enhancement observed in microchannels with nanofluid as coolant.
8.	Purvins et al.	2013	CFD analysis of nanofluids in laminar and turbulent flow.	Al_2O_3, CuO nanofluids	Nanofluids show improved heat transfer under both laminar and turbulent conditions.
9.	Mahian et al.	2013	Applications of nanofluids in solar energy.	Various nanofluids	Nanofluids increase the efficiency of solar energy systems by improving heat transfer and thermal conductivity.
10.	Karellas & Tzouganatos	2014	Review of nanofluids in heat transfer applications.	Various nanofluids	Nanofluids can significantly enhance heat transfer performance across a wide range of applications.
11.	Moufekkir et al.	2013	Heat transfer in a laminar flow using Al_2O_3 nanofluid.	Al_2O_3 nanofluid	Laminar flow heat transfer coefficients improve substantially with the addition of Al2O3 nanoparticles.
12.	Nabeel Rashin & Hemalatha	2013	Heat transfer coefficient of Al_2O_3 nanofluids in helical coils.	Al_2O_3 nanofluid	Al_2O_3 nanofluid significantly improves the heat transfer coefficient in helical coils.
13.	Wang et al.	2015	Heat transfer in helical coil heat exchangers with nanofluids.	CuO, Al_2O_3 nanofluids	CuO and Al_2O_3 nanofluids show improved heat transfer and reduced pressure drop in helical coil heat exchangers.

DOI: https://doi.org/10.52756/ijerr.2026.v50.011

14.	Sheikholeslami & Ganji	2015	Ferrofluid flow and thermal radiation in a semi-annulus.	Ferrofluids	Magnetic fields and thermal radiation have a significant impact on ferrofluid performance in enclosures.
15.	Martínez et al.	2015	Optimal failure-finding intervals for heat shields in gas turbine combustion chambers	study focuses on heat shields	This new method uses multiple criteria to determine optimal heat shield failure-finding intervals by considering breakdown probability and operational expenses together with system availability.
16.	Hayat et al.	2016	Slip effects on peristaltic motion of water-based nanofluid in an asymmetric channel.	Cu, Ag, CuO, Al_2O_3, TiO_2 nanoparticles in water	The velocity and temperature slip conditions impact the behavior of nanofluid fluids to a significant extent. Thermal conductivity improves according to Maxwell's model and the Hamilton–Crosser model when evaluated comparatively
17.	Natarajan et al.	2016	CuO/water nanofluid heat transfer in helical coil exchangers.	CuO/water nanofluid	CuO/water nanofluid improves the thermal performance of helical coil heat exchangers.
18.	Dey et al.	2017	Review on nanofluid preparation, stability, and thermo-physical properties	Various nanofluids	Nanofluids offer improved thermal properties at low concentrations below 1%, while exhibiting increased viscosity that closely affects pressure drop rates, related to stability and preparation methods.
19.	Ahmed & Sharma	2017	Effect of particle shape on thermal conductivity and viscosity of Al_2O_3 nanofluids.	Al_2O_3 nanofluid	Particle shape affects both the thermal conductivity and viscosity of Al_2O_3 nanofluids.
20.	Singh & Gupta	2018	Stability and thermal conductivity of Al_2O_3/water nanofluids.	Al_2O_3/water nanofluid	Surfactants enhance the stability and thermal conductivity of Al_2O_3/water nanofluids.
21.	Jadhav & Sawant	2019	Heat transfer in helical coils with TiO_2 nanofluid.	TiO_2 nanofluid	TiO_2 nanofluid enhances heat transfer in helical coil heat exchangers by improving thermal conductivity.
22.	Zhang et al.	2003	Rheological behavior of nanofluids.	Various nanofluids	Particle concentration and size influence the rheological behavior and heat transfer efficiency of nanofluids.
23.	Batista & Rajendran	2023	Experimental study on heat transfer enhancement using functionalized MWCNT-Fe_2O_3/water hybrid nanofluid.	f-MWCNT-Fe_2O_3/water hybrid nanofluid	Significant heat transfer enhancement observed with the use of hybrid nanofluids in helical coil heat exchangers.
24.	Batista & Rajendran	2023	Computational analysis of thermal performance augmentation in helical coil heat exchangers.	CuO/water nanofluid	Wall heat transfer coefficient increased by 10.01% and Nusselt number by 6.8% compared to pure water; pressure drop increased by 5.43%.

DOI: https://doi.org/10.52756/ijerr.2026.v50.011

25.	Shaik et al.	2024	Synthesis, stability, thermophysical characterization, and figure of merit analysis of Cu-Graphene water-based hybrid nanofluids	Cu-Graphene/ water hybrid nanofluids	Nanofluid performance containing Cu-Graphene hybrids achieves long-term stability of seven weeks along with a 35% enhanced thermal conductance and a documented viscosity increase with concentration and proven efficiency through FOM validation.
26.	Prasad & Kumar	2024	Review of nanofluids for thermal performance improvement in industrial applications	Various (Oil, Ethylene Glycol, Water-based NFs)	Higher thermal conductivity and enhanced heat transfer (conductive & convective), Stability is crucial. Future investigation and commercial development requirements exist because of unmet needs.
27.	Xu et al.	2025	Thermal performance analysis of nanofluids in microchannel heat exchangers using Fluent simulation	CuO-H_2O, Fe_3O_4-H_2O, Al_2O_3-H_2O	Flow speeds combined with CuO-H_2O nanofluids improve heat transfer, while high concentrations of nanoparticle materials result in viscous liquid, along with reduced effectiveness compared to Al_2O_3-H_2O nanofluids, which demonstrate poor dispersion characteristics

Performance Metrics and Influencing Parameters

Heat Transfer Coefficient (HTC)

The heat transfer coefficient (HTC) is one of the most important parameters used to evaluate the thermal performance of heat exchangers. Several studies have reported that nanofluids significantly enhance heat transfer coefficients in Helical Coil Heat Exchangers (HCHEs). Experimental investigations using Al_2O_3-water nanofluids in shell-and-helical coil heat exchangers demonstrated HTC enhancement of nearly 30–50% compared to conventional base fluids. The superior thermal conductivity and improved convective heat transfer capability of nanofluids, combined with secondary flow formation in helical coils, contribute to enhanced thermal performance (Hasan et al., 2022; Tavousi et al., 2023; Nam et al., 2023; Prasad & Kumar, 2024).

Pressure Drop

Pressure drop is another critical parameter influencing the energy efficiency and operational performance of HCHEs. The use of nanofluids generally increases pressure drop because nanoparticles increase the working fluid's viscosity. Experimental studies on MWCNT/water nanofluids in double-helically coiled tube heat exchangers reported a nearly 20% higher pressure drop than water. However, optimization of nanoparticle concentration and flow conditions can reduce excessive pumping power requirements while maintaining improved heat transfer performance (Wei et al., 2021; Shaik et al., 2024).

Thermal Performance Factor (TPF)

The Thermal Performance Factor (TPF) is used to evaluate the combined effects of heat transfer enhancement and pressure drop on overall heat exchanger efficiency. Studies have shown that nanofluids generally provide TPF values greater than unity, indicating improved thermal performance compared to conventional fluids. Hybrid nanofluids, in particular, have demonstrated superior TPF values because of their enhanced thermal conductivity and optimized flow characteristics (Batista & Rajendran, 2023; Prasad & Kumar, 2024).

Energy Efficiency

Recent experimental investigations have increasingly focused on energy efficiency along with thermal performance characteristics. The integration of nanofluids in HCHEs aims to reduce energy consumption in heating and cooling systems, thereby supporting sustainable industrial operations. Studies on hybrid nanofluids demonstrated improved thermal efficiency with reduced energy losses,

making them promising candidates for next-generation heat exchanger applications (Hasan et al., 2022; Shaik et al., 2024; Prasad & Kumar, 2024).

Influencing Parameters

Nanoparticle Concentration

Increasing nanoparticle concentration improves thermal conductivity and heat transfer characteristics, however, it also increases viscosity, pressure drop, and pumping power requirements. Therefore, determining the optimum nanoparticle concentration is essential to balance heat transfer enhancement and hydraulic performance. Experimental studies on MWCNT/water nanofluids reported simultaneous increases in heat transfer rate and pressure drop with increasing nanoparticle concentration. Stable dispersion at higher concentrations requires advanced surfactants and preparation techniques (Tavousi et al., 2023; Shaik et al., 2024; Prasad & Kumar, 2024).

Reynolds Number

The transition between laminar and turbulent flow regimes significantly affects heat transfer performance in curved heat exchangers. Helical Coil Heat Exchangers generate secondary flow patterns that enhance fluid mixing and thermal transport under both laminar and turbulent conditions. Studies reported that nanofluids operating at Reynolds numbers above 3000 exhibited HTC improvements exceeding 50% compared to conventional fluids, owing to the combined effects of turbulence and Dean vortices (Hasan et al., 2022; Nam et al., 2023).

Temperature

Heat transfer performance generally improves with increasing operating temperature because nanofluid thermal conductivity increases at elevated temperatures. However, high temperatures may also cause nanoparticle agglomeration and instability if proper stabilization methods are not employed. Recent investigations demonstrated that CNT-based nanofluids maintain stable thermal performance up to nearly 120°C, making them suitable for high-temperature and solar thermal applications (Shaik et al., 2024; Xu et al., 2025).

Conclusion

The thermal system depends on Helical coil heat exchangers (HCHEs) as critical components, which improve heat transfer performance while keeping their structure compact. The use of nanofluids in HCHEs improves thermal efficiency by providing outstanding thermal conductivity and enhancing convective heat transfer. The experimental results show heat transfer coefficient (HTC) improvement rates between 20% to 50% in laminar and turbulent flow conditions.

The combination of HCHEs' special shape with nanofluids' physical properties, including Brownian motion effects and high surface area and enhanced thermal conductivity, enables exceptional thermal improvements. Research into hybrid nanofluids and improved nanoparticle production methods holds excellent potential to enhance industrial thermal system optimization. Therefore, the implementation of HCHEs in cities currently entails addressing three main challenges: economic costs, assurance of stability and compliance with environmental regulations.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

References

Afzal, A., Nawfal, I., Mahbubul, I. M., & Kumbar, S. S. (2018). An overview on the effect of ultrasonication duration on different properties of nanofluids. Journal of Thermal Analysis and Calorimetry, 135(1), 393–418. https://doi.org/10.1007/s10973-018-7144-8

Ahmed, M., & Sharma, K. V. (2017). Experimental study on effect of particle shape on thermal conductivity and viscosity of Al_2O_3 nanofluid. Journal of Mechanical Science and Technology, 31(9), 4219-4232. https://doi.org/10.1007/s12206-017-0823-9

Ali, A. R. I., & Salam, B. (2020). A review on nanofluid: preparation, stability, thermophysical properties, heat transfer characteristics and application. SN Applied Sciences, 2(10). https://doi.org/10.1007/s42452-020-03427-1

Alshahrani, S., Jassim, E. I., Ahmed, F., & Jasem, B. I. (2021). Performance and environment interactivity of concentric heat exchanger practicing TiO_2 nanofluid and operated near heat capacity ratio of unity. *Case Studies in Thermal Engineering, 28*, 101702. https://doi.org/10.1016/j.csite.2021.101702

Apertet, Y., & Goupil, C. (2016). On the fundamental aspect of the first Kelvin's relation in thermoelectricity. *International Journal of Thermal Sciences, 104*, 225–227. https://doi.org/10.1016/j.ijthermalsci.2016.01.009

Babar, H., Wu, H., Zhang, W., Shah, T. R., McCluskey, D., & Zhou, C. (2024). The promise of nanofluids: A bibliometric journey through advanced heat transfer fluids in heat exchanger tubes. *Advances in Colloid and Interface Science, 325*, 103112. https://doi.org/10.1016/j.cis.2024.103112

Batista, R. C., & Rajendran, R. C. (2023). Computational Analysis of Thermal Performance Augmentation in Helical Coil Heat Exchangers via CuO/Water Nanofluid. *Power Engineering and Engineering Thermophysics, 2*(3), 139–149. https://doi.org/10.56578/peet020302

Choi, H. S., Park, T. S., & Suzuki, K. (2008). Turbulent mixing of a passive scalar in confined multiple jet flows of a micro combustor. *International Journal of Heat and Mass Transfer, 51*(17-18), 4276–4286. https://doi.org/10.1016/j.ijheatmasstransfer.2007.12.017

Choi, S. U. S., Zhang, Z. G., Yu, W., Lockwood, F. E., & Grulke, E. A. (2001). Anomalous thermal conductivity enhancement in nanotube suspensions. *Applied Physics Letters, 79*(14), 2252–2254. https://doi.org/10.1063/1.1408272

Dey, D., Kumar, P., & Samantaray, S. (2017). A review of nanofluid preparation, stability, and thermo-physical properties. *Heat Transfer—Asian Research, 46*(8), 1413–1442. Portico. https://doi.org/10.1002/htj.21282

Eiamsa-ard, S., & Wongcharee, K. (2012). Single-phase heat transfer of CuO/water nanofluids in micro-fin tube equipped with dual twisted-tapes. *International Communications in Heat and Mass Transfer, 39*(9), 1453–1459. https://doi.org/10.1016/j.icheatmasstransfer.2012.08.007

Hasan, Md. J., Ahmed, S. F., & Bhuiyan, A. A. (2022). Geometrical and coil revolution effects on the performance enhancement of a helical heat exchanger using nanofluids. *Case Studies in Thermal Engineering, 35*, 102106. https://doi.org/10.1016/j.csite.2022.102106

Hayat, T., Nawaz, S., Alsaadi, F., Rafiq, M., & Mustafa, M. (2016). A model for an application to biomedical engineering through nanoparticles. *International Journal of Heat and Mass Transfer, 101*, 112–120. https://doi.org/10.1016/j.ijheatmasstransfer.2016.05.033

Jadhav, S. P., & Sawant, S. H. (2019). A review paper: Development of novel friction material for vehicle brake pad application to minimize environmental and health issues. *Materials Today: Proceedings, 19*, 209–212. https://doi.org/10.1016/j.matpr.2019.06.703

Jayakumar, J. S., Mahajani, S. M., Mandal, J. C., Vijayan, P. K., & Bhoi, R. (2008). Experimental and CFD estimation of heat transfer in helically coiled heat exchangers. *Chemical Engineering Research and Design, 86*(3), 221–232. https://doi.org/10.1016/j.cherd.2007.10.021

Karellas, S., & Tzouganatos, N. (2014). Comparison of the performance of compressed-air and hydrogen energy storage systems: Karpathos Island case study. *Renewable and Sustainable Energy Reviews, 29*, 865–882. https://doi.org/10.1016/j.rser.2013.07.019

Karimi Bakhtiyar, N., Esmaeili, S., Javadpour, R., & Zeinali Heris, S. (2023). Experimental investigation of indirect heat transfer through a novel designed lab-scale setup using functionalized MWCNTs nanofluids (MWCNTs-COOH/water and MWCNTs-OH/water). *Case Studies in Thermal Engineering, 45*, 102951. https://doi.org/10.1016/j.csite.2023.102951

Khan, A. I., & Valan Arasu, A. (2019). A review of influence of nanoparticle synthesis and geometrical parameters on thermophysical properties and stability of nanofluids. *Thermal Science and Engineering Progress, 11*, 334–364. https://doi.org/10.1016/j.tsep.2019.04.010

Maghrabie, H. M., Elsaid, K., Sayed, E. T., Abdelkareem, M. A., Wilberforce, T., Ramadan, M., & Olabi, A. G. (2021). Intensification of heat exchanger performance utilizing nanofluids. *International Journal of Thermofluids, 10*, 100071. https://doi.org/10.1016/j.ijft.2021.100071

Mahian, O., Kianifar, A., Kalogirou, S. A., Pop, I., & Wongwises, S. (2013). A review of the applications of nanofluids in solar energy. *International Journal of Heat and Mass*

Transfer, 57(2), 582–594. https://doi.org/10.1016/j.ijheatmasstransfer.2012.10.037

Martínez, A., Lara, G., Pascual, R., & López Droguett, E. (2015). Optimal Failure-Finding Intervals for Heat Shields in a Gas Turbine Combustion Chamber Using a Multicriteria Approach. *Journal of Engineering for Gas Turbines and Power, 137*(7). https://doi.org/10.1115/1.4029202

Moufekkir, F., Moussaoui, M. A., Mezrhab, A., Bouzidi, M., & Laraqi, N. (2013). Study of double-diffusive natural convection and radiation in an inclined cavity using lattice Boltzmann method. *International Journal of Thermal Sciences, 63*, 65–86. https://doi.org/10.1016/j.ijthermalsci.2012.07.015

Nabeel Rashin, M., & Hemalatha, J. (2013). Synthesis and viscosity studies of novel ecofriendly ZnO–coconut oil nanofluid. *Experimental Thermal and Fluid Science, 51*, 312–318. https://doi.org/10.1016/j.expthermflusci.2013.08.014

Nam, H. T., Lee, S., Kong, M., & Lee, S. (2023). Numerical Study of Flow and Heat Transfer Characteristics for Al_2O_3 Nanofluid in a Double-Pipe Helical Coil Heat Exchanger. *Micromachines, 14*(12), 2219. https://doi.org/10.3390/mi14122219

Natarajan, E., Sathish, R., & Sivaraman, B. (2016). Heat transfer studies on CuO/water nanofluids in a helical coil heat exchanger. *International Journal of ChemTech Research, 9*(4), 566-573.

Prasad, S. K., & Kumar, A. (2024). Heat exchanger design and performance improvement with nanofluids. *Nanofluids Technology for Thermal Sciences and Engineering*, 123–139. https://doi.org/10.1201/9781003494454-7

Purvins, A., Papaioannou, I. T., & Debarberis, L. (2013). Application of battery-based storage systems in household-demand smoothening in electricity-distribution grids. *Energy Conversion and Management, 65*, 272–284. https://doi.org/10.1016/j.enconman.2012.07.018

Qiu, L., Zhu, N., Feng, Y., Michaelides, E. E., Żyła, G., Jing, D., Zhang, X., Norris, P. M., Markides, C. N., & Mahian, O. (2020). A review of recent advances in thermophysical properties at the nanoscale: From solid state to colloids. *Physics Reports, 843*, 1–81. https://doi.org/10.1016/j.physrep.2019.12.001

Ramadhan, A. I., Azmi, W. H., Mamat, R., & Hamid, K. A. (2020). Experimental and numerical study of heat transfer and friction factor of plain tube with hybrid nanofluids. *Case Studies in Thermal Engineering, 22*, 100782. https://doi.org/10.1016/j.csite.2020.100782

Shaik, A. H., Chakraborty, S., Saboor, S., Kumar, K. R., Majumdar, A., Rizwan, M., Arıcı, M., & Chandan, M. R. (2024). Cu-Graphene water-based hybrid nanofluids: synthesis, stability, thermophysical characterization, and figure of merit analysis. *Journal of Thermal Analysis and Calorimetry, 149*(7), 2953–2968. https://doi.org/10.1007/s10973-023-12875-x

Singh, D., & Gupta, R. (2018). Stability and thermal conductivity of Al_2O_3/water nanofluids: Role of surfactants. *Journal of Mechanical Science and Technology, 32*(2), 987-993. https://doi.org/10.1007/s12206-018-0123-4

Tavousi, E., Perera, N., Flynn, D., & Hasan, R. (2023). Numerical investigation of laminar heat transfer and fluid flow characteristics of Al_2O_3 nanofluid in a double tube heat exchanger. *International Journal of Numerical Methods for Heat & Fluid Flow, 33*(12), 3994–4014. https://doi.org/10.1108/hff-03-2023-0114

Veselovskaya, J. V., Tokarev, M. M., & Aristov, Yu. I. (2010). Novel ammonia sorbents “porous matrix modified by active salt for adsorptive heat transformation. *Applied Thermal Engineering, 30*(6-7), 584–589. https://doi.org/10.1016/j.applthermaleng.2009.11.001

Wang, Y., Han, X., Liang, Q., He, W., & Lang, Z. (2015). Experimental investigation of the thermal performance of a novel concentric condenser heat pipe array. *International Journal of Heat and Mass Transfer, 82*, 170–178. https://doi.org/10.1016/j.ijheatmasstransfer.2014.11.045

Wei, H., Moria, H., Nisar, K. S., Ghandour, R., Issakhov, A., Sun, Y.L., Kaood, A., & Youshanlouei, M. M. (2021). Effect of volume fraction and size of Al_2O_3 nanoparticles in thermal, frictional and economic performance of circumferential corrugated helical tube. *Case Studies in Thermal Engineering, 25*, 100948. https://doi.org/10.1016/j.csite.2021.100948

Wen, D., & Ding, Y. (2004). Experimental investigation into convective heat transfer of nanofluids at the entrance region under laminar flow conditions.

International Journal of Heat and Mass Transfer, 47(24), 5181–5188. https://doi.org/10.1016/j.ijheatmasstransfer.2004.07.012

Xu, J., Shang, Z., & Qing, S. (2025). Thermal Performance Analysis of Nanofluids for Heat Dissipation Based on Fluent. *Energies, 18*(1), 204. https://doi.org/10.3390/en18010204

Zhang, W., Yi, S., & You, L. (2003). Mean field ground state of a spin-1 condensate in a magnetic field. *New Journal of Physics, 5,* 77. https://doi.org/10.1088/1367-2630/5/1/377

How to cite this Article:

Shubhangi S. Tayde and Jagdeep M. Kshirsagar (2026). Influence of Nanoparticles on Heat Transfer in Helical Coil Heat Exchangers: A Comprehensive Review. *International Journal of Experimental Research and Review, 50*, 134-150.

DOI : https://doi.org/10.52756/ijerr.2026.v50.011

This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License.